ENGIN STORAGE

UNIVERSITY OF ILLINOIS BULLETIN
Issued Weekly
Vol. XXVIII November 11, 1930 No. 11
[Entered as second-class matter, December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Acceptance for mailing at the special rate of postage provided for in section 1103, Act of October 3, 1917, authorized July 31, 1918.]

TESTS OF WELDS

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

THE CHICAGO BRIDGE AND IRON WORKS

BY

WILBUR M. WILSON

LIBRARY
JUN 20 1931
UNIVERSITY OF TORONTO

CIRCULAR No. 21
ENGINEERING EXPERIMENT STATION

Published by the University of Illinois, Urbana

Price: Twenty Cents

THE Engineering Experiment Station was established by act of the Board of Trustees of the University of Illinois on December 8, 1903. It is the purpose of the Station to conduct investigations and make studies of importance to the engineering, manufacturing, railway, mining, and other industrial interests of the State.

The management of the Engineering Experiment Station is vested in an Executive Staff composed of the Director and his Assistant, the Heads of the several Departments in the College of Engineering, and the Professor of Industrial Chemistry. This Staff is responsible for the establishment of general policies governing the work of the Station, including the approval of material for publication. All members of the teaching staff of the College are encouraged to engage in scientific research, either directly or in coöperation with the Research Corps composed of full-time research assistants, research graduate assistants, and special investigators.

To render the results of its scientific investigations available to the public, the Engineering Experiment Station publishes and distributes a series of bulletins. Occasionally it publishes circulars of timely interest, presenting information of importance, compiled from various sources which may not readily be accessible to the clientele of the Station.

The volume and number at the top of the front cover page are merely arbitrary numbers and refer to the general publications of the University. *Either above the title or below the seal* is given the number of the Engineering Experiment Station bulletin or circular which should be used in referring to these publications.

For copies of bulletins or circulars or for other information address

THE ENGINEERING EXPERIMENT STATION,
UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

CIRCULAR NO. 21 NOVEMBER, 1930

TESTS OF WELDS

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

THE CHICAGO BRIDGE AND IRON WORKS

BY

WILBUR M. WILSON
RESEARCH PROFESSOR OF STRUCTURAL ENGINEERING

ENGINEERING EXPERIMENT STATION

PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA, ILLINOIS

Digitized by the Internet Archive
in 2011 with funding from
University of Toronto

5500 3 31 9967

UNIVERSITY
OF ILLINOIS
PRESS

http://www.archive.org/details/bulletin21univ

CONTENTS

PAGE

I. INTRODUCTION 5
  1. Object and Scope of Investigation 5
  2. Acknowledgments 5

II. PHYSICAL PROPERTIES OF MATERIAL IN WELD . . . 6
  3. Description of Specimens 6
  4. Results of Tests 8

III. COMPARISON OF VARIOUS TYPES OF WELDED BUTT JOINTS 13
  5. Description of Specimens 13
  6. Results of Tests 16

IV. TESTS OF WELDED LAP JOINTS 23
  7. Description of Specimens 23
  8. Results of Tests 23

V. COMPARISON OF JOINTS MADE WITH VARIOUS WELD-RODS 27
  9. Description of Specimens 27
  10. Results of Tests 29

VI. SUMMARY 34
  11. Summary 34

LIST OF FIGURES

NO. PAGE
1. Specimens for Determining Physical Properties of Material in Weld—Weld-Rod No. 16 6
2. Specimens for Determining Physical Properties of Material in Weld—Weld-Rod No. 18 7
3. Stress-Strain Diagrams for Material in Weld—Specimens Made of Weld-Rod No. 16 and Beads Longitudinal with Specimen 9
4. Stress-Strain Diagrams for Material in Weld—Specimens Made of Weld-Rod No. 16 and Beads Transverse to Specimen 10
5. Stress-Strain Diagrams for Material in Weld—Specimens Made of Weld-Rod No. 18 11
6. Character of Fracture of Material in Weld—Weld-Rod No. 16 . . . 13
7. Tension Specimens of All-Weld Material after Fracture—Specimens Having Longitudinal Beads, Weld-Rod No. 16 14
8. Tension Specimens of All-Weld Material after Fracture—Specimens Having Longitudinal Beads, Weld-Rod No. 18 15
9. Tension Specimens of All-Weld Material after Fracture—Specimens Having Transverse Beads, Weld-Rod No. 18 15
10. Types of Welded Joints 16
11. Specimens L1 after Failure 19
12. Specimens L3 after Failure 20
13. Specimens L4 after Failure 21
14. Specimens L11 after Failure 22
15. Specimens for Tests of Lap Joints 24
16. Relation between Stress and Deflection of Plate due to Eccentricity—Offset Specimen 26
17. Relation between Stress and Deflection of Plate due to Eccentricity—Lap-Welded Specimen 26
18. Location of Specimens in Parent Plate 27
19. Fractured Sections of Specimens Welded by Chicago Bridge and Iron Works 35
20. Fracture Section, Series 9. 35
21. Fracture Section, Series 15 36
22. Fracture Section, Series 18 36

LIST OF TABLES

1. Physical Properties of Material in Weld 12
2. Strength of Various Types of Welded Butt Joints 17
3. Strength of Lap-Welded Joints 25
4. Chemical Composition of Weld-Rods 28
5. Shop Log of Welds Made by Chicago Bridge and Iron Works 29
6. Strength of Welds Made with Rods from Various Companies 30
7. Strength of Welds Made with Rods from Various Companies 32
8. Summary of Tests. 34

TESTS OF WELDS

I. INTRODUCTION

1. *Object and Scope of Investigation.*—The investigation reported in this circular pertains only to hand-welding of the relatively thin steel plates used in the fabrication of storage tanks for oil and water systems. It is realized that the processes used are not so carefully controlled as the machine welding used in the standardized manufacture of large numbers of duplicate articles that are produced by automatic machinery. Nevertheless they are processes that are in general use for the purposes for which they have been developed, and information relative to the quality of weld obtained is of particular value at this time when the art of welding is developing so rapidly.

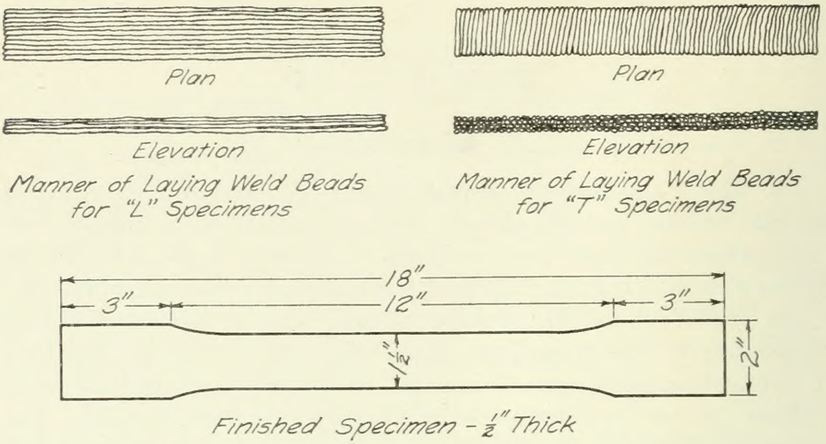
The objects of the investigation were to determine the physical properties of a weld-rod after it has been deposited in a weld, the relative merits of various types of welds for thin plates, and the relative merits of various types of weld-rods.

The investigation has been limited to electric-arc welds and to static tests of welds.

2. *Acknowledgments.*—This investigation is a part of the work of the Engineering Experiment Station of the University of Illinois, of which DEAN MILO S. KETCHUM is the director, and the Department of Civil Engineering, of which PROF. W. C. HUNTINGTON is the head. The work was financed by the CHICAGO BRIDGE AND IRON WORKS, who furnished the specimens and provided funds from which to pay the direct expenses. Much of the testing was done by JAMES MATHER, Research Graduate Assistant in Civil Engineering.

The work was done in consultation with an Advisory Committee of the Chicago Bridge and Iron Works, the members of which are: H. C. Boardman, Chairman; George T. Horton; O. A. Bailey; E. E. Michals, and Ralph Green.

Weld-rods were contributed by the following companies:
The Lincoln Electric Co.
Hollup Corporation
Reid Avery Co.
Koro Corporation



Manner of Laying Weld Beads for "L" Specimens

Manner of Laying Weld Beads for "T" Specimens

Finished Specimen - ½" Thick

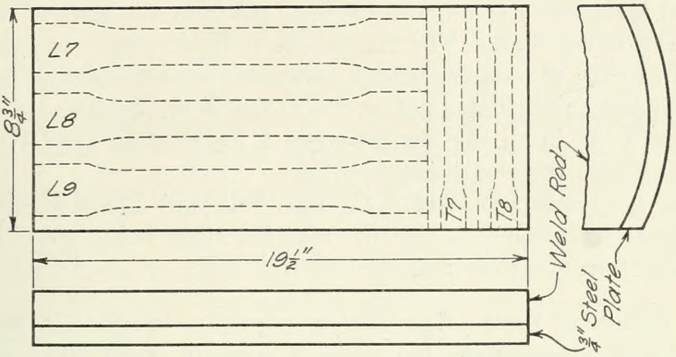
FIG. 1. SPECIMENS FOR DETERMINING PHYSICAL PROPERTIES OF MATERIAL IN WELD—WELD-ROD NO. 16

Fusion Welding Corporation
Quasi-Arc, Inc.
Steel Sales Corporation
Central Steel & Wire Co.
John A. Roebling's Sons & Co.
Una Welding & Bonding Co.

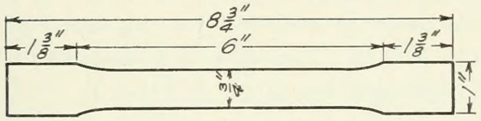
II. PHYSICAL PROPERTIES OF MATERIAL IN WELD

3. *Description of Specimens.*—The object of this investigation was to determine the physical properties of the material in a weld-rod after it has been melted with an electric arc and deposited as in a weld. The specimens were composed entirely of weld steel, and were made by building up a slab consisting of a number of layers of beads laid one upon the other. Tension specimens were cut from the slab and machined on all sides to the desired dimensions.

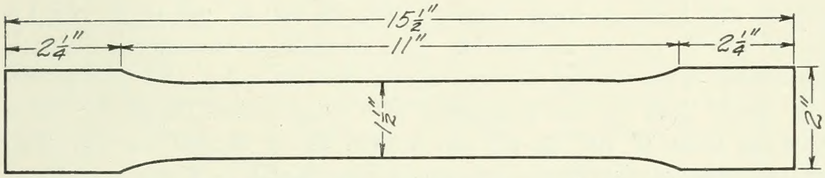
Specimens were made from two weld-rods, No. 16 and No. 18, Table 4. Both rods were furnished by the same company and the body of both had the same composition, as shown in the table. The No. 16 was an uncoated rod, whereas No. 18 had a coating designed to produce a reducing atmosphere over the molten metal. The slabs made of No. 16 rod were laid by a welder in the employ of the Chicago Bridge and Iron Works and the specimens were machined by



(a)-Slab from which Specimens were Cut.



(b)-Specimens T7 and T8 - ¼" Thick



(c)-Specimens L7, L8, and L9, - ½" Thick

FIG. 2. SPECIMENS FOR DETERMINING PHYSICAL PROPERTIES OF MATERIAL IN WELD—WELD-ROD NO. 18

the same company; the slabs made of No. 18 rod were laid by the company furnishing the rod.

Two slabs were made of the No. 16 rod; one slab was cut so that the beads were longitudinal with the specimen and the other so that the beads were transverse to the specimen. The former specimens were numbered L1 to L6 and the latter T1 to T6. The dimensions of the finished specimen and the manner of laying the beads are illustrated in Fig. 1.

Figure 2a shows a slab made of the No. 18 rod as it was received at the laboratory. The weld-material had been laid on a curved steel plate to a depth at the middle of approximately one inch. Transverse specimens, numbered T7 and T8, were cut from one end and longitudinal specimens L7, L8, and L9 were cut from the body of the slab as shown in the figure. The dimensions of the finished specimens are shown in Figs. 2b and 2c. The T specimens were made only one-half as wide and one-half as thick as the L specimens because the former were used to obtain the elongation in 4 in. whereas the latter were used to obtain the elongation in 8 in.

The specimens L11, L12, L13, T11, T12, and T13 were cut from additional slabs made of No. 18 rod, the slabs being made by the company furnishing the rod.

4. *Results of Tests.*—The tension specimens described in Section 3 were tested to determine the ultimate strength, yield point, relation between stress and strain, reduction in area, and elongation. The stress-strain diagrams are shown in Figs. 3, 4, and 5, Figs. 3 and 4 being for specimens made of weld-rod No. 16, and Fig. 5 for specimens from weld-rod No. 18. The physical properties of the material as determined by these tests are given in Table 1.

Specimens Made of Uncoated Rod No. 16

The strength of the specimens with longitudinal beads is both consistent and high, its value ranging from 53 900 lb. per sq. in. for L3 to 59 800 lb. per sq. in. for L6. The strength of the specimens with transverse beads varied through a considerable range and was generally lower than for the specimens with longitudinal beads, its value varying from 37 100 lb. per sq. in. for T2 to 51 100 for T4. The character of the fractures is shown in Figs. 6 and 7. There were flaws in all of the specimens with transverse beads, and in many cases these flaws covered a large portion of the fractured section. The flaws in the specimens with longitudinal beads were much smaller. The yield point for most specimens was high relative to the ultimate strength.

The modulus of elasticity had about the same value for all specimens, varying from 25 700 000 to 29 800 000 lb. per sq. in. The specimens with longitudinal beads were more ductile than those with transverse beads, but Fig. 7 shows that even the former were much less ductile than tank or structural steel.

Specimens Made of Coated Rod No. 18

The strength of the specimens with longitudinal beads was quite uniform, the values of the ultimate strength for the three specimens of the first slab being 59 800, 58 100, and 54 100 lb. per sq. in., respectively, and of the second slab 53 234, 54 239, and 51 890 lb. per sq. in., respectively. The strength for the specimens with transverse

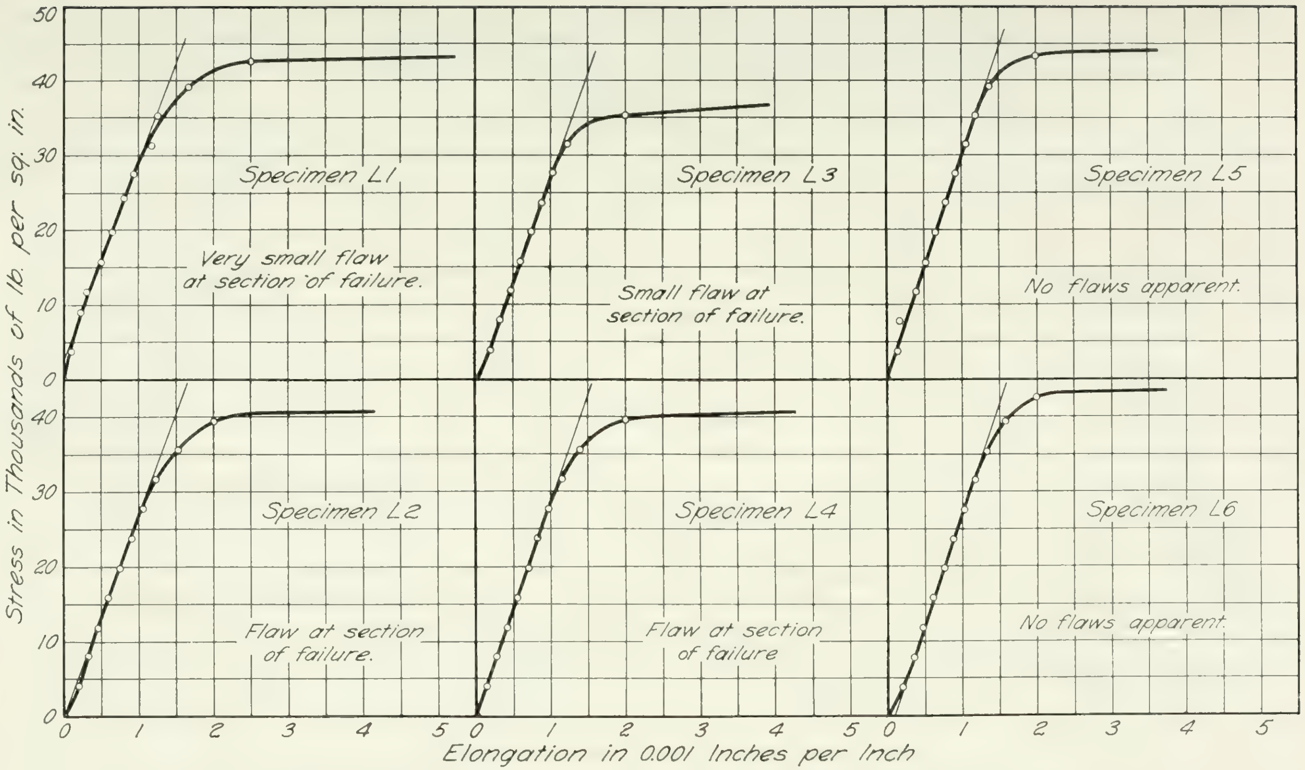


FIG. 3. STRESS-STRAIN DIAGRAMS FOR MATERIAL IN WELD—SPECIMENS MADE OF WELD-ROD NO. 16 AND BEADS LONGITUDINAL WITH SPECIMEN

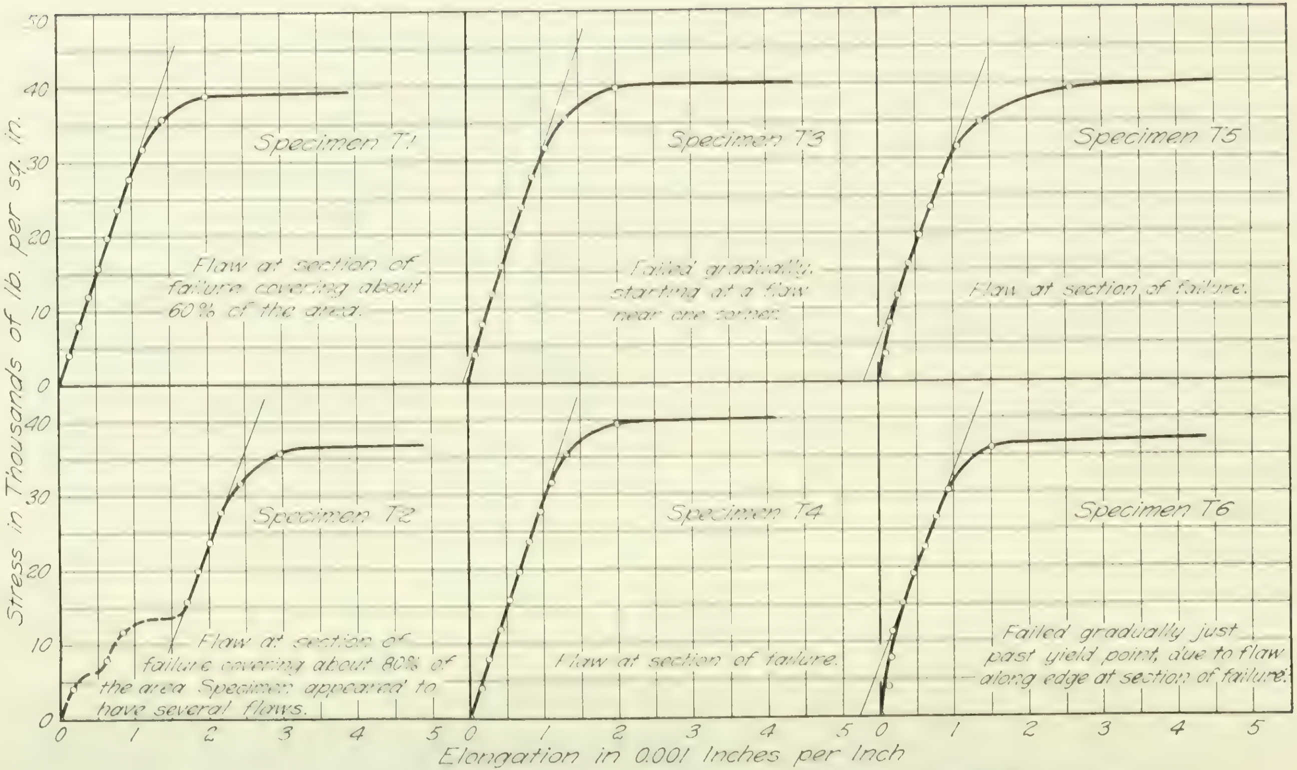


FIG. 4. STRESS-STRAIN DIAGRAMS FOR MATERIAL IN WELD—SPECIMENS MADE OF WELD-ROD NO. 16 AND BEADS TRANSVERSE TO SPECIMEN

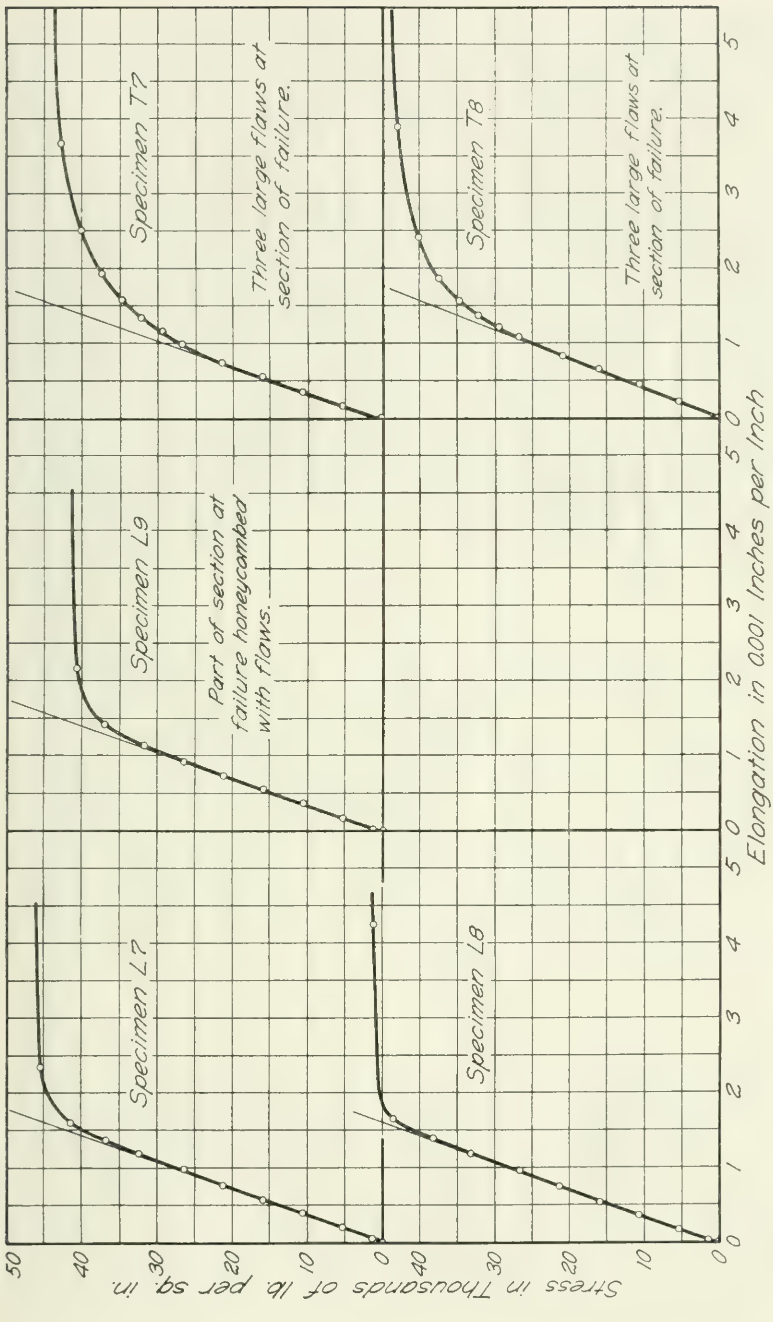


Fig. 5. Stress-Strain Diagrams for Material in Weld—Specimens Made of Weld-Rod No. 18

Table 1
Physical Properties of Material in Weld

Specimen No.		Ultimate Strength lb. per sq. in.	Yield Pt. lb. per sq. in.	Reduction of Area per cent	Elongation in 8 in. per cent	Modulus of Elasticity lb. per sq. in.
Uncoated Rod No. 16						
Longitudinal Beads	L1	58 500	42 700	7.61	7.63	26 500 000
	L2	57 200	42 100	11.58	7 87	27 600 000
	L3	53 900	35 450	8.53	8.00	28 700 000
	L4	56 500	39 500	8 43	7 50	28 700 000
	L5	59 100	44 400	11.42	10 00	29 300 000
	L6	59 800	42 700	14.18	9.13	29 600 000
	Av.	57 500	41 140	10.29	8.36	28 400 000
Transverse Beads	T1	50 100	38 900	7.65	4.00	28 400 000
	T2	37 100	37 100	3.84	1.00	25 700 000
	T3	41 100	39 400	8.15	3.63	28 800 000
	T4	51 100	39 400	6.70	3.63	29 800 000
	T5	43 100	37 300	3.53	2.25	26 250 000
	T6	37 400	36 700	7.84	1.63	26 100 000
	Av.	43 314	38 130	6.28	2.69	27 508 000
Coated Rod No. 18, First Slab						
Longitudinal Beads	L7	59 800	46 500	25.30	14.78	28 100 000
	L8	58 100	46 200	25.40	14.65	27 300 000
	L9	54 100	42 100	25.20	9.11	27 300 000
	Av.	57 300	44 930	25.30	12.85	27 600 000
Transverse Beads	T7	51 050	43 500	16.31	8.07*	28 100 000
	T8	53 700	43 700	30.00	9.18*	25 500 000
	Av.	52 375	43 600	23.15	8.62*	26 800 000
Coated Rod No. 18, Second Slab						
Longitudinal Beads	L11	53 234	33 296	33.8	16.6	27 600 000
	L12	54 239	35 205	29.9	15.4	28 000 000
	L13	51 890	33 605	32.8	13.6	28 600 000
	Av.	53 121	34 035	32.2	15.2	28 067 000
Transverse Beads	T11	54 188	35 242	26.8	15.3	29 800 000
	T12	53 144	34 360	34.9	17.1	28 100 000
	T13	54 146	34 353	33.4	15.8	29 000 000
	Av.	53 583	34 651	31.7	16.1	28 967 000

*Elongation in 4 inches.

beads was higher than for the corresponding specimens made of the uncoated rods, the values for the specimens from the first slab being 51 050 and 53 700 lb. per sq. in., and of the second slab being 54 188, 53 144, and 54 146 lb. per sq. in. The character of the fractures is shown in Figs. 8 and 9. The specimens made from the No. 18 rod were more ductile than those made from the No. 16 rod. This is apparent both from the elongation and reduction of area and also from the appearance of the specimens after fracture. The specimens made of the No. 18 rod had the appearance of a ductile material containing

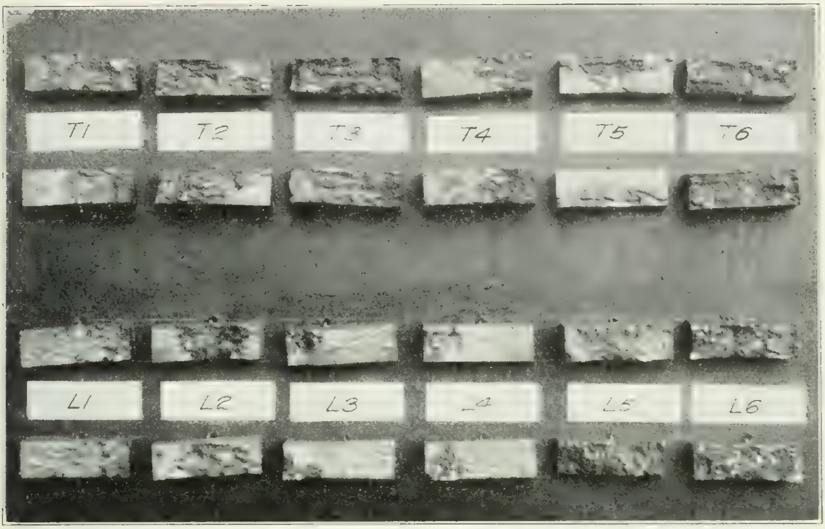


Fig. 6. Character of Fracture of Material in Weld—Weld-Rod No. 16

minute globular voids and inclusion of small particles of less ductile material. The yield point for all specimens was high relative to the ultimate strength. The modulus of elasticity varied from 27 300 000 to 28 600 000 lb. per sq. in. for the specimens with longitudinal beads and from 25 500 000 to 29 800 000 lb. per sq. in. for the specimens with transverse beads.

The apparatus used for determining the stress-strain relation was calibrated to this extent: Before being used on the all-weld specimens it was used on a piece of steel of structural grade and gave for this steel a stress-strain relation corresponding to a modulus of elasticity of between 29 000 000 and 30 000 000 lb. per sq. in.

III. Comparison of Various Types of Welded Butt Joints

5. *Description of Specimens.*—The object of this series of tests was to determine the relative merits of various types of joints. Seven types, all illustrated in Fig. 10a, were used. The finished specimens had the same dimensions as the one shown in Fig. 1, except the control specimens which were only half as long. The excess material in the joint was not removed, so that in general the area of the specimen was greater through the weld than through the parent metal.

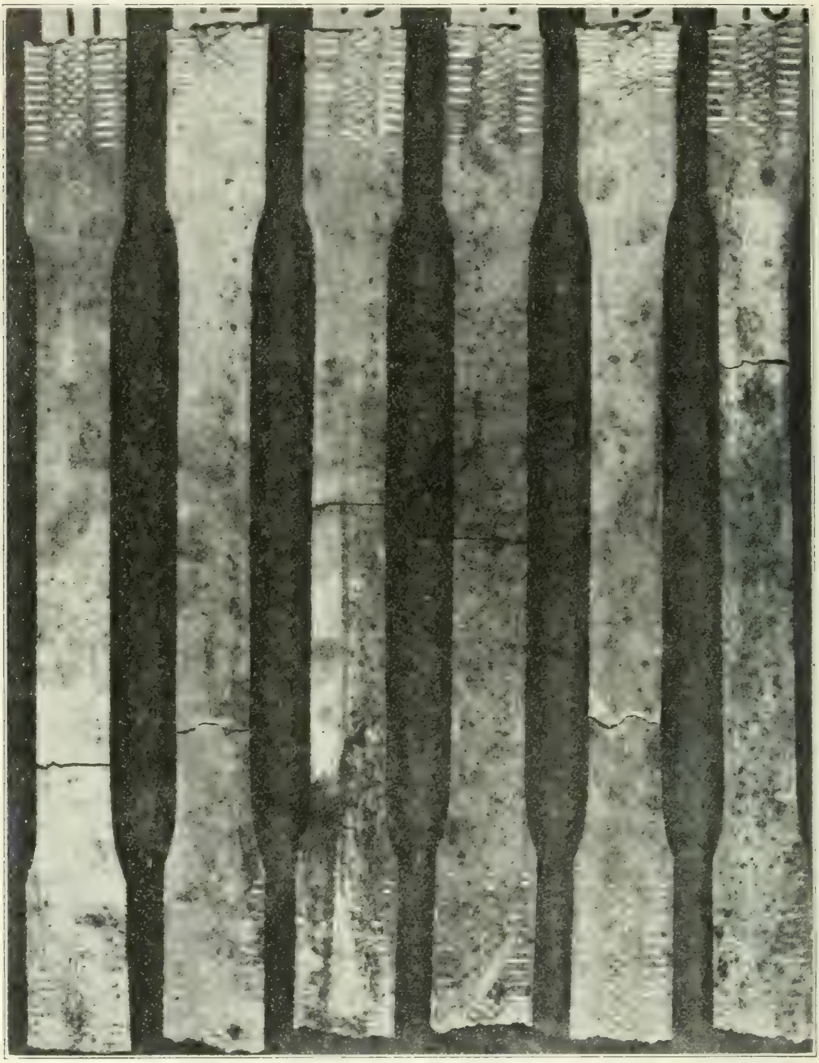


Fig. 7. Tension Specimens of All-Weld Material after Fracture—Specimens Having Longitudinal Beads, Weld-Rod No. 16

Except for two types of joints, marked L1 and L10, there were six welded specimens and two control specimens for each type. When the specimens marked L1 and L10 were made they warped considerably and another set of six specimens of each type was made, care

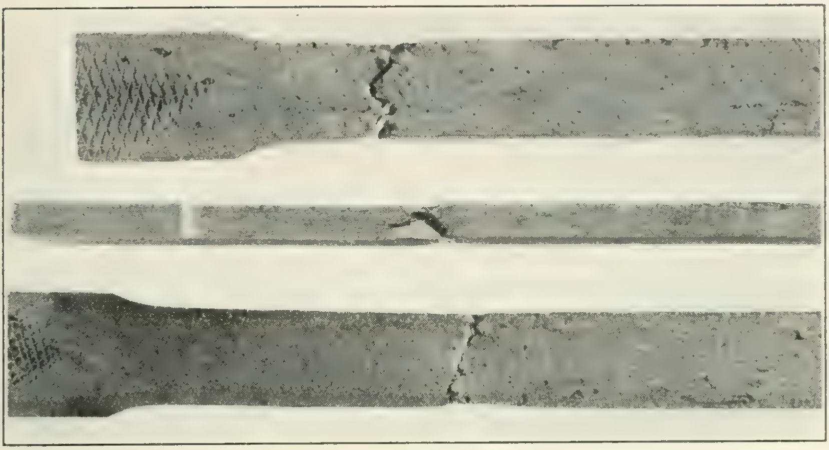


Fig. 8. Tension Specimens of All-Weld Material after Fracture—Specimens Having Longitudinal Beads, Weld Rod No. 18

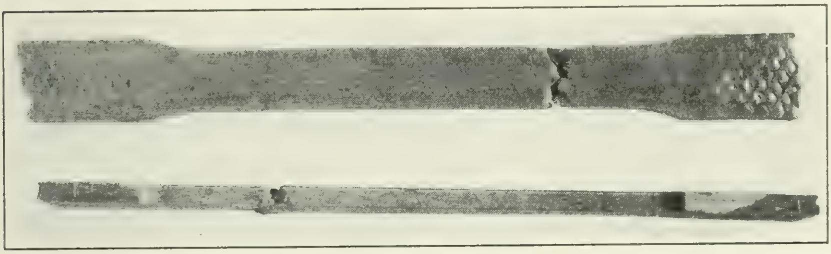
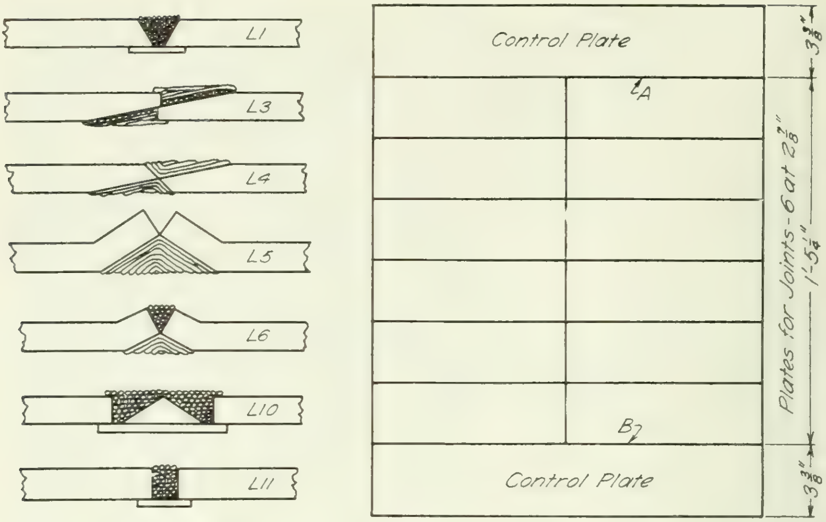


Fig. 9. Tension Specimens of All-Weld Material after Fracture—Specimens Having Transverse Beads, Weld-Rod No. 18

being taken to prevent warping. These latter specimens, marked L1A and L10A, brought the total number for each of these types to twelve welded specimens and four control specimens.

The relative position of the specimens in the original plate is illustrated in Fig. 10b. A plate 20 x ½ x 24 in. long was used for each group of specimens. Two strips 3⅜ in. wide, one cut from each end, were machined to form control specimens for determining the physical properties of the plate to be welded. The remaining portion of the plate was then cut along the line connecting *A* and *B*, and then the two edges, originally in contact, were machined and welded together. This plate was then cut into strips 2⅞ in. wide, and each strip was machined to the dimensions shown in Fig. 1. In this way all specimens having



(a)-Types of Joints (b)-Details for Cutting Plates

FIG. 10. TYPES OF WELDED JOINTS

the same type of joint were welded as a continuous weld so that an agreement among the specimens of a group would indicate uniformity along a joint in a wide plate.

All specimens were welded with the same weld-rod and all welds were made by the same workman, a welder regularly employed by the Chicago Bridge and Iron Works.

The sketch in Fig. 10 and the photographs reproduced in Fig. 11 show a plate attached to some specimens. This is a backing-up plate that retains the metal while the beads are being laid and is not intended to constitute a part of the joint. The specimens used in the tests of joints of the L1 type, described in Sections 9 and 10, had the excess weld material and the backing-up plate removed before the specimens were tested.

6. *Results of Tests.*—The manner of failure, yield point, and ultimate strength, for the specimens in the series to determine the relative merits of various types of joints, are listed in Table 2. Reproductions of photographs of the specimens after failure are shown in Figs. 11 to 14, inclusive. Of the joints of the V-type, the six marked L1 all broke outside of the weld, five of the six marked L1A broke outside of the weld, the sixth failed at the edge of the weld at an

TABLE 2
STRENGTH OF VARIOUS TYPES OF WELDED BUTT JOINTS

Specimen No.	Yield Point lbs.		Ult. Strength lbs.		Remarks
	Total	Per sq. in.	Total	Per sq. in.	
L1-1	23 250	31 062	41 250	55 110	Failed Outside of Weld
L1-2	22 950	31 585	41 210	56 716	Failed Outside of Weld
L1-3	24 130	32 630	41 350	55 916	Failed Outside of Weld
L1-4	24 900	34 298	40 545	55 847	Failed Outside of Weld
L1-5	25 150	34 357	41 290	56 407	Failed Outside of Weld
L1-6	24 345	33 172	40 360	54 994	Failed Outside of Weld
Av.				55 830	
L1-7	23 980	32 648	41 640	56 692	Control Specimen
L1-8	23 930	31 928	42 090	56 157	Control Specimen
Av.				56 425	
L1A1	23 100	30 475	39 870	52 599	Failed Outside of Weld
L1A2	23 850	31 485	39 760	52 488	Failed Outside of Weld
L1A3	23 650	31 159	40 110	52 846	Failed Outside of Weld
L1A4	23 100	30 535	39 710	52 492	Failed Outside of Weld
L1A5	23 950	31 722	39 050	51 722	Failed at Edge of Weld
L1A6	23 430	30 972	39 610	52 360	Failed Outside of Weld
Av.				52 417	
L1A7	19 820	26 374	39 550	52 628	Control Specimen
L1A8	19 800	26 139	39 560	52 224	Control Specimen
Av.				52 426	
L3-1	22 370	29 029	40 560	52 634	Failed Outside of Weld
L3-2	22 530	30 611	41 340	56 168	Failed Outside of Weld
L3-3	23 240	30 987	41 530	55 373	Failed Outside of Weld
L3-4	23 950	32 497	40 700	55 244	Failed Outside of Weld
L3-5	23 160	31 553	40 130	54 673	Failed Outside of Weld
L3-6	23 870	32 344	41 420	56 125	Failed Outside of Weld
Av.				55 036	
L3-7	23 130	30 319	40 930	53 677	Control Specimen
L3-8	22 970	31 418	41 270	56 449	Control Specimen
Av.				55 063	
L4-1	23 200	31 479	41 820	56 744	Failed Outside of Weld
L4-2	22 910	30 918	41 170	55 560	Failed Outside of Weld
L4-3	23 160	31 318	40 580	54 875	Failed Outside of Weld
L4-4	24 300	33 039	40 890	55 595	Failed Outside of Weld
L4-5	23 870	32 454	40 450	54 997	Failed Outside of Weld
L4-6	24 740	33 455	41 100	55 578	Failed Outside of Weld
Av.				55 558	
L4-7	22 950	30 930	41 550	55 997	Control Specimen
L4-8	23 670	32 143	41 260	56 029	Control Specimen
Av.				56 013	
L5-1	23 280	31 566	41 250	55 932	Failed Outside of Weld
L5-2	23 200	31 120	41 730	55 976	Failed Outside of Weld
L5-3	22 930	30 799	41 200	55 339	Failed Outside of Weld
L5-4	24 855	33 793	41 250	56 084	Failed Outside of Weld
L5-5	24 445	33 236	41 600	56 560	Failed Outside of Weld
L5-6	23 845	32 158	41 445	55 893	Failed in Weld
Av.				55 964	
L5-7	22 560	30 568	41 500	56 232	Control Specimen
L5-8	23 890	32 240	42 280	57 058	Control Specimen
Av.				56 645	

TABLE 2—*Concluded*

Specimen No.	Yield Point lbs.		Ult. Strength lbs.		Remarks
	Total	Per sq. in.	Total	Per sq. in.	
L6–1	23 450	32 036	37 090	50 669	Failed at Edge of Weld
L6–2	24 170	33 087	38 270	52 389	Failed in Weld
L6–3	22 570	30 854	36 840	50 362	Failed at Edge of Weld
L6–4	23 560	32 120	40 430	55 119	Failed at Edge of Weld
L6–5	22 600	30 686	38 990	52 940	Failed at Edge of Weld
L6–6	23 840	32 391	39 680	53 913	Failed at Edge of Weld
Av.				52 565	
L6–7	23 200	31 246	42 040	56 620	Control Specimen
L6–8	22 130	29 946	41 310	55 900	Control Specimen
Av.				56 260	
L10–1	23 950	32 786	41 230	56 441	Failed at Edge of Weld
L10–2	22 690	31 018	40 970	56 008	Failed at Edge of Weld
L10–3	23 680	32 376	41 530	56 781	Failed at Edge of Weld
L10–4	24 900	34 175	40 310	55 325	Failed Outside of Weld
L10–5	24 700	33 628	39 900	54 323	Failed at Edge of Weld
L10–6	24 015	33 074	40 860	56 273	Failed Outside of Weld
Av.				55 858	
L10–7	23 300	31 233	42 020	56 327	Control Specimen
L10–8	23 010	31 542	41 520	56 916	Control Specimen
Av.				56 622	
L10A1	23 070	29 977	36 210	47 050	Failed at Edge of Weld
L10A2	24 050	31 209	40 430	52 466	Failed at Edge of Weld
L10A3	23 550	30 426	40 010	51 693	Failed Outside of Weld
L10A4	24 250	31 762	38 070	49 862	Failed at Edge of Weld
L10A5	25 200	32 813	39 910	51 966	Failed Outside of Weld
L10A6	23 030	29 944	36 060	46 886	Failed at Edge of Weld
Av.				49 987	
L10A7	20 490	26 659	39 670	51 613	Control Specimen
L10A8	20 220	26 308	39 720	51 678	Control Specimen
Av.				51 645	
L11-1	22 100	29 526	41 020	54 803	Failed Outside of Weld
L11-2	24 630	33 016	41 740	55 952	Failed Outside of Weld
L11-3	23 450	31 540	41 290	55 535	Failed Outside of Weld
L11-4	24 400	33 475	40 210	55 165	Failed Outside of Weld
L11-5			21 900	29 679	Failed at Edge of Weld
L11-6	23 860	32 645	33 630	46 012	Failed at Edge of Weld
Av.				49 520	
L11-7	22 980	31 096	41 520	56 184	Control Specimen
L11-8	23 120	31 264	41 570	56 214	Control Specimen
Av.				56 200	

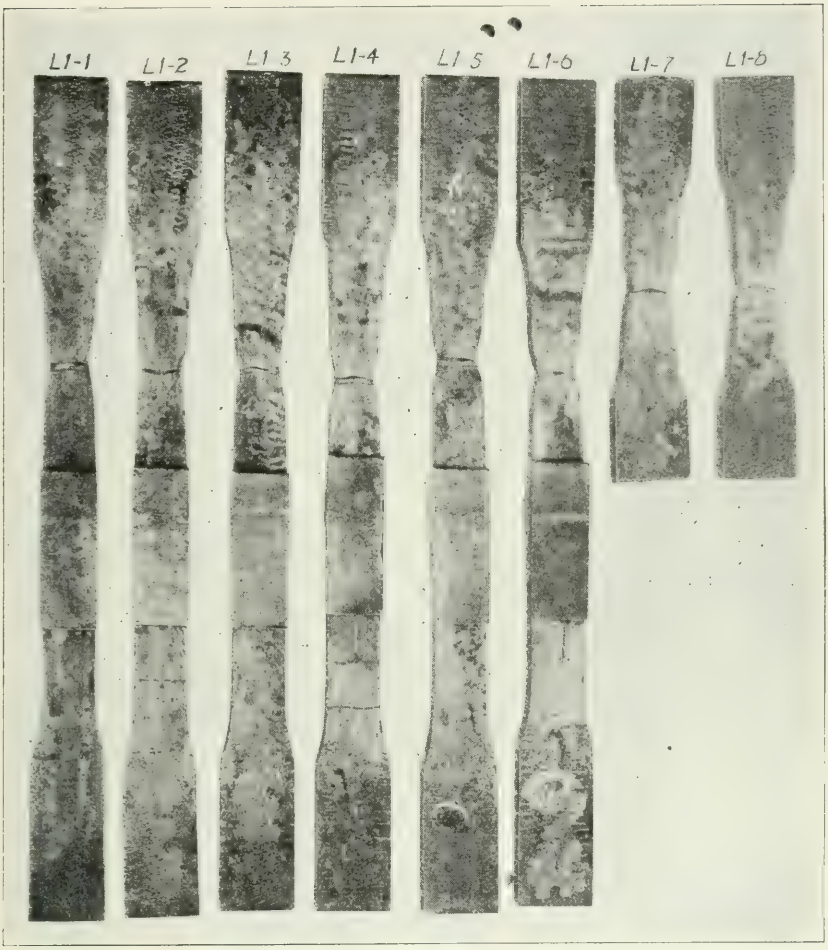


FIG. 11. SPECIMENS L1 AFTER FAILURE

ultimate strength 835 lb. per sq. in., or 1.6 per cent, less than the average strength of the five that failed outside of the weld. The six L3 and the six L4 joints all failed outside of the weld; one out of six of the L5 specimens failed in the weld and at a stress 85 lb. per sq. in. less than the average strength of the five specimens that failed outside of the weld; all six of the L6 joints failed either in or at the edge of the weld, and at an average load 3695 lb. per sq. in. less than the average strength of the control specimens, and the weakest

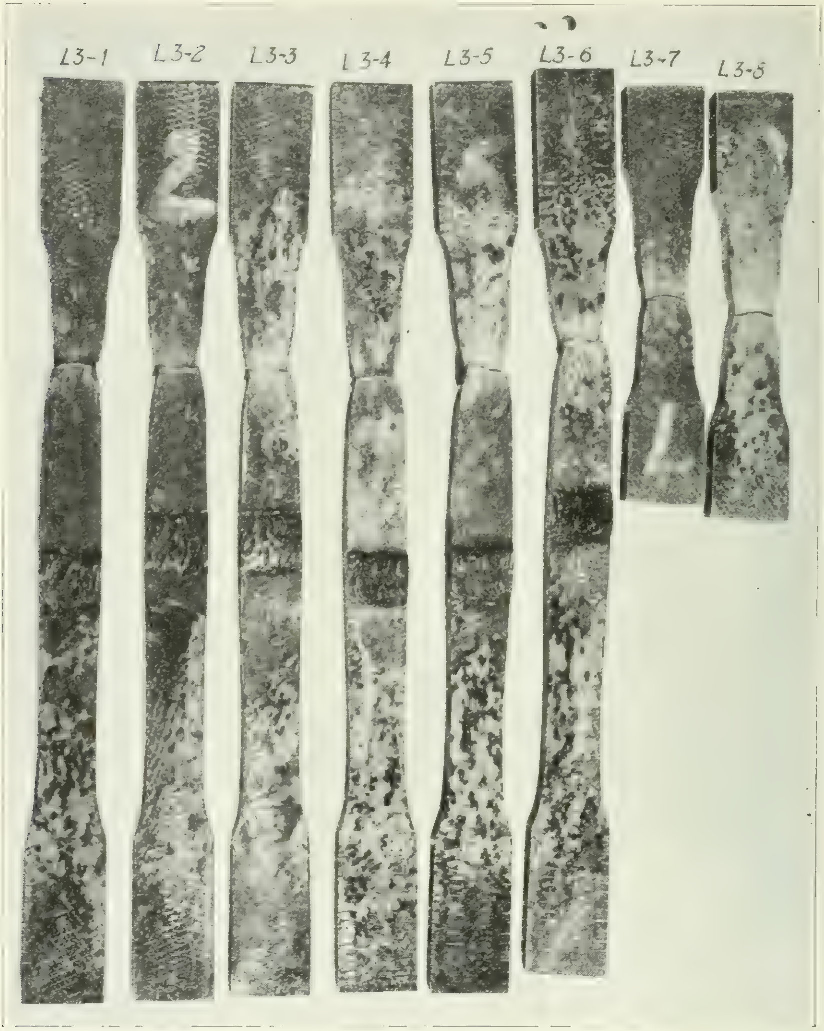


Fig. 12. Specimens L3 after Failure

specimen developed 50 362 lb. per sq. in.; four of the six L10 specimens failed at the edge of the weld, but at loads almost equal to the strength of the control specimens; four of the six L10A specimens failed at the edge of the weld, the weakest specimens having a strength of 46 886 lb. per sq. in.; four of the six L11 specimens failed outside

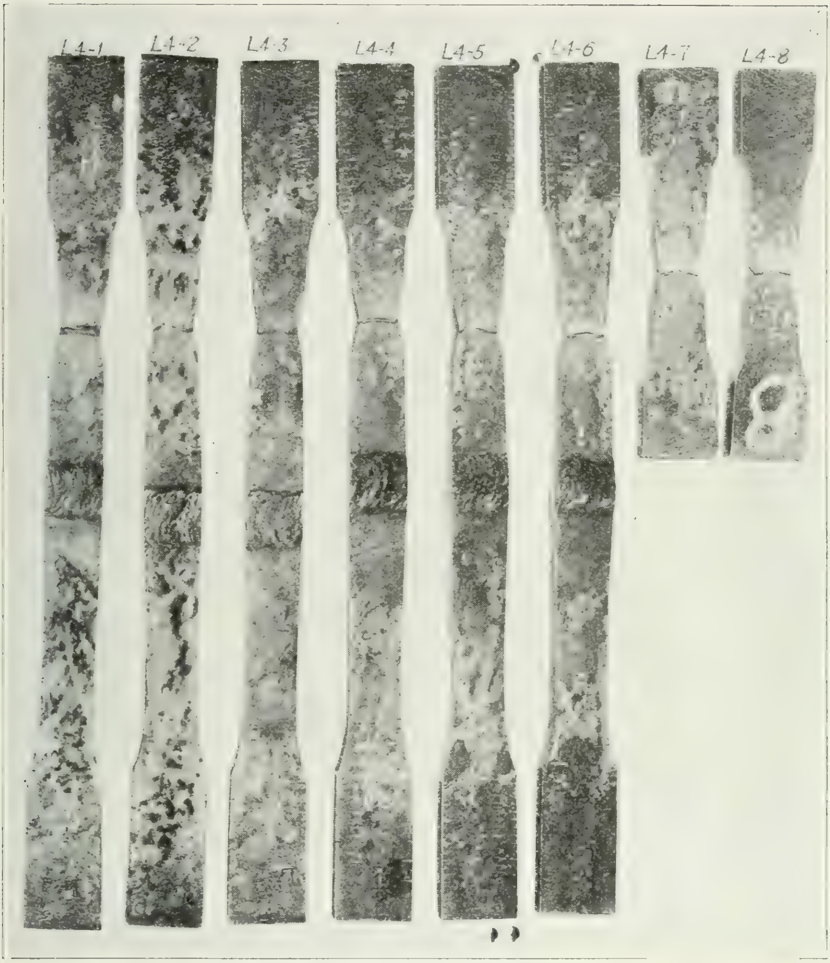


Fig. 13. Specimens L4 after Failure

of the weld, two failed at the edge of the weld at loads of 29 679 and 46 012 lb. per sq. in., respectively.

The two most desirable features in a welded joint are (1) ease and cheapness of manufacture, and (2) strength of the joint. Types L1 and L11 are the easiest to manufacture. The L3 and L4 joints were a little stronger than the L1 joints in this series, but the difference was so slight as to be of little significance, especially since the tests described in Sections 9 and 10 indicate that there are weld-rods

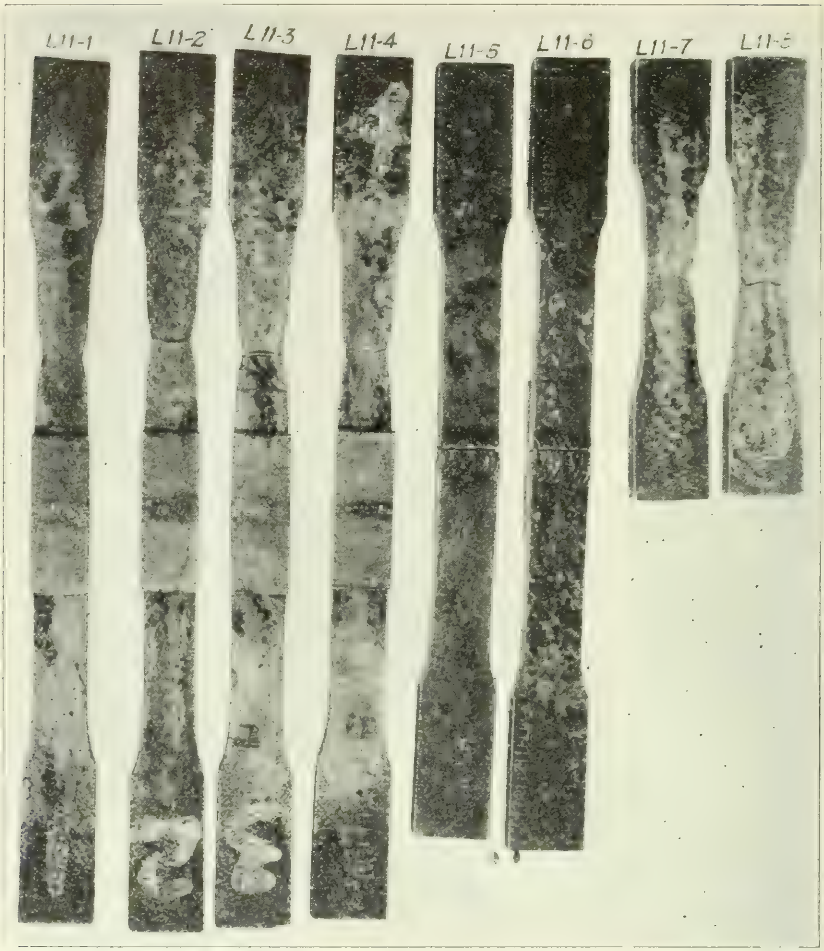


Fig. 14. Specimens L11 after Failure

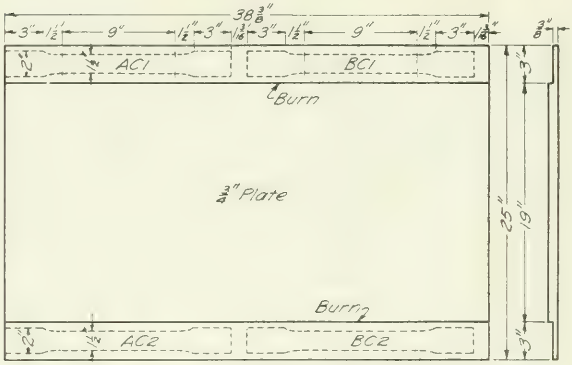
available with which welds of the L1 type can be consistently made that will develop the full strength of plates of structural grade. This being true, there would seem to be no justification for using the more expensive L3 and L4 types. The other easily constructed type of joint, L11, proved to be inferior to L1. Considering the ease of manufacture and the strength of the welds, joints of the type L1, Fig. 10, would appear to be the most desirable of the types tested for connecting thin plates.

IV. Tests of Welded Lap Joints

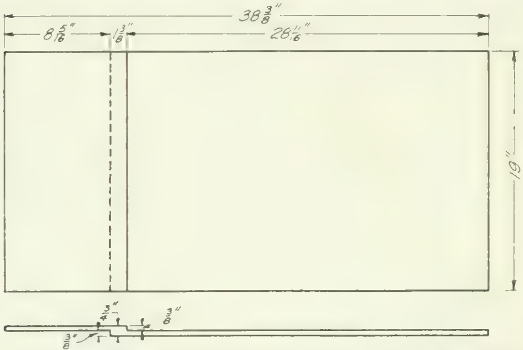
7. *Description of Specimens.*—The object of these tests was to determine the strength of lap-welded joints in plates. Three types of specimens were used, two types of control specimens and one welded specimen. One type of control specimen was the usual flat tension specimen used to determine the physical properties of the parent plate. The second type of control specimen was similar to the first except that, instead of the surface being a plane for the full length of the specimen, there was an offset near the middle of the specimen equal to its thickness. The purpose of this type of control specimen was to determine the effect of eccentricity in the case of a specimen composed of continuous material containing no weld or other type of joint.

The method of making the specimens from a plate is illustrated in Fig. 15. All specimens, including the three types, were cut from the single plate 25 x ¾ x 38⅜ in., shown in Fig. 15a. The first operation was to plane a strip 3 in. wide along each edge to a thickness of ⅜ in. These thin strips were then burned off and machined to form the control specimens, AC1, AC2, BC1, and BC2 from which the physical properties of the plate were determined. The main body of the plate was machined to the dimensions shown in Fig. 15b and then cut along the line *AA*, Fig. 15c. The left-hand portion was cut into the tension specimens A1 to A6 that have the same eccentricity as a specimen containing a lap-joint but that are, really, continuous material. These constituted the second type of control specimens. The portion of the plate to the right of the line *AA* was cut along the line *BB* and machined to the lines *CC* and *DD*. The two portions were connected with a lap-weld made with weld-rod No. 16, Table 4, and then cut into the tension specimens B1 to B6. These tests were planned on the assumption that any difference in strength between the specimens AC1, AC2, BC1, and BC2 and the specimens A1 to A6 is attributable to the eccentricity, and any difference in the strength of the specimens A1 to A6 and the specimens B1 to B6 is attributable to the weld.

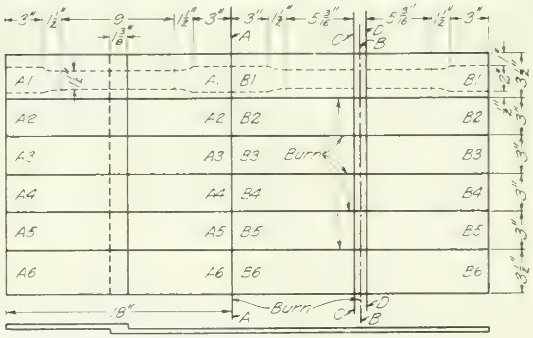
8. *Results of Tests.*—All specimens were tested to determine the yield point and ultimate strength, and the offset specimens were tested to determine the relation between the stress and the bending of the specimen. The results of the tests are given in Table 3. All offset specimens broke at a distance two inches or more from the offset, the average strength being slightly less than that of the straight specimens, but the difference is so small that it has no particular significance. All lap-welded specimens broke two inches or more from the



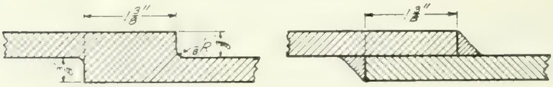
(a)-Details for Cutting Control Plates AC1, AC2, BC1 & BC2



(b)-Preparation of Remainder of Plate for Specimens



(c)-Details for Cutting Specimens



"A" Specimen

"B" Specimen

(d)-Details of Specimens

FIG. 15. SPECIMENS FOR TESTS OF LAP JOINTS

TABLE 3
STRENGTH OF LAP-WELDED JOINTS

Type of Spec.	Spec. No.	Dimensions			Yield Point		Ultimate Strength		Elong. in 8 in. per cent	Reduction of area per cent
		Width in.	Thickness in.	Area sq. in.	Total	Lb. per sq. in.	Total	Lb. per sq. in.		
Straight Control	AC1	1.510	0.383	0.578	16 890	29 220	32 720	56 600	24.75	51.5
	AC2	1.510	0.370	0.558	18 890	33 850	32 310	57 900	26.37	51.6
	BC1	1.504	0 379	0.570	16 280	28 560	32 780	57 500	28.75	47.5
	BC2	1.509	0.369	0.557	18 780	33 710	32 570	58 470	24.63	45.5
	Av.					31 325		57 367	26.12	46.1
Offset Control	A1	1.494	0.376	0.562	16 625	29 580	31 865	56 690		
	A2	1.499	0.377	0.565	17 080	30 230	32 090	56 790		
	A3	1.499	0.382	0.573	16 970	29 610	31 990	55 820		
	A4	1.499	0.387	0.580	16 850	26 050	32 190	55 500		
	A5	1.495	0.383	0.572	16 930	29 590	32 260	56 390		
	A6	1.494	0.385	0.575	17 110	29 750	32 230	56 050		
	Av.					29 135		56 210		
Lap Welded	B1	1.502	0.382	0.574	27 500	47 900	32 715	56 990		
					16 780*	29 380				
	B2	1.502	0.380	0.571	27 250	47 720	32 725	57 310		
					20 680	36 150				
	B3	1.503	0.381	0.572	29 190	51 030	33 125	57 910		
					19 190	33 600				
	B4	1.500	0.381	0.571	29 550	51 750	32 950	57 700		
					16 610	29 030				
	B5	1.498	0.382	0.572	26 010	45 470	33 000	57 690		
	B6	1.500	0.380	0.570	16 840	29 540				
					27 215	47 740	33 080	58 030		
						31 490				
	Av.					48 600		57 605		

*Larger yield point is of weld; the smaller is of the parent metal. All breaks were outside of weld.

welds and their average strength was slightly greater than the average strength of the straight control specimens.

There were two yield points for the lap-welded specimens, one the yield point of the parent material, and the other the yield point of the weld. The deformation of the weld appeared to be a shear deformation, and it permitted one plate to slide upon the other. This relative motion was of the order of 0.02 to 0.03 in. at the ultimate load.

The relation between the unit stress in the specimen and the deflection of the plate due to eccentricity is shown in Figs. 16 and 17. The deflection was measured with an Ames dial in the manner illustrated in the figures. The diagrams indicate that deflection began at a very small stress, and varied directly as the stress at the low loads. The stress at which the slope of the tangent to the stress-deflection diagram is 50 per cent greater than its value at zero stress is indicated on each of the curves. This "proportionality" limit is quite consistent and has an average value of 10 400 lb. per sq. in. for the offset specimens and of 13 150 lb. per sq. in. for the lap-welded specimens.

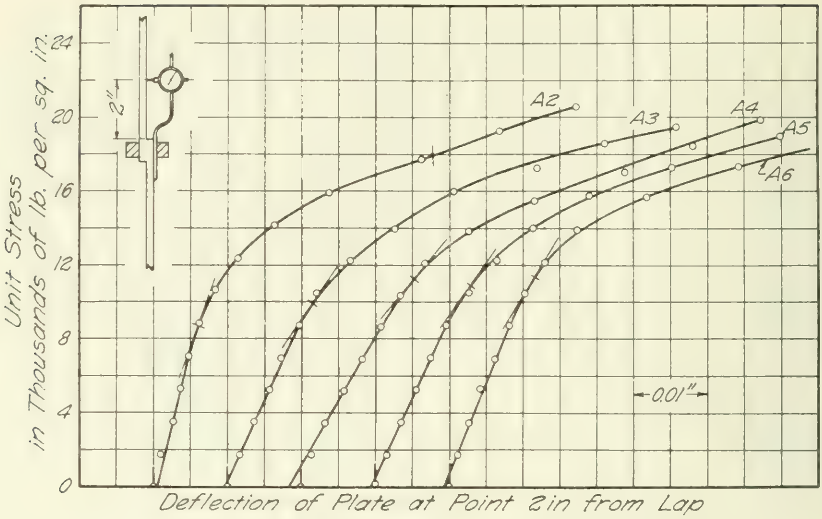


Fig. 16. Relation between Stress and Deflection of Plate due to Eccentricity—Offset Specimen

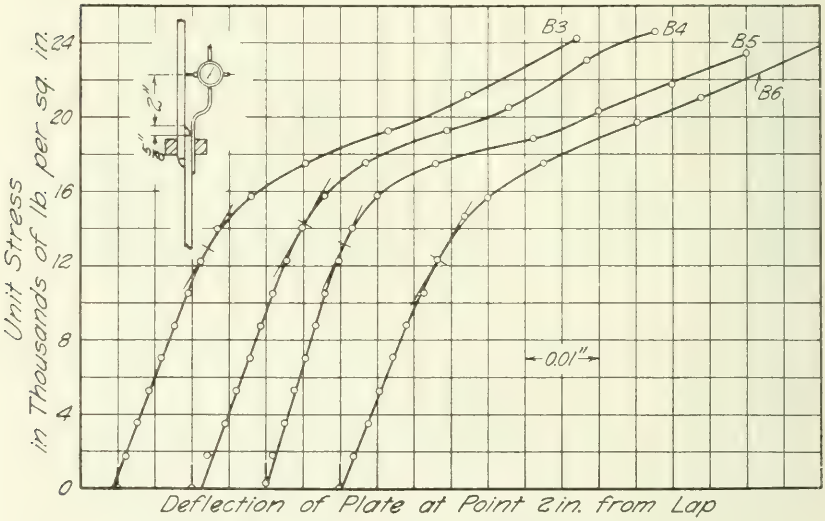
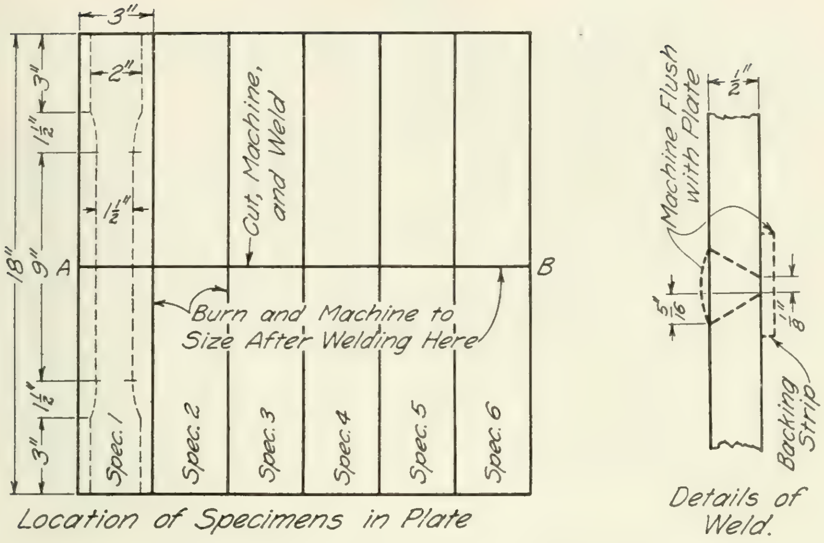


Fig. 17. Relation between Stress and Deflection of Plate due to Eccentricity—Lap-Welded Specimen



Location of Specimens in Plate

Details of Weld.

FIG. 18. LOCATION OF SPECIMENS IN PARENT PLATE

These tests seem to indicate that the eccentricity of a lap joint does not materially affect the ultimate strength of the joint, but that the eccentricity does produce a deflection in the plate that begins to increase rapidly with the stress when the stress equals 12 000 to 13 000 lb. per sq. in. for plates ⅜ in. thick. The six specimens containing lap welds made of weld-rod No. 16 all broke outside of the weld, and all developed a strength approximately equal to the strength of the parent plate.

V. COMPARISON OF JOINTS MADE WITH VARIOUS WELD-RODS

9. *Description of Specimens.*—The object of this series of tests was to determine the relative merits of various weld-rods. All joints were of the V type, L1, Fig. 10. The manner of obtaining the specimens is illustrated in Fig. 18. A plate originally 18 in. square and ½ in. thick was cut along the line *AB* and the edges of the two pieces, originally in contact, were machined and welded. The plate was then cut into strips 3 in. wide, and the strips were machined to the dimensions shown. The backing-up plate and the excess weld material were ma-

TABLE 4
CHEMICAL COMPOSITION OF WELD-RODS
All values are in per cent

Series No.	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Remarks
1	....	....	....	....	....	Fine aluminum flux wire laid alongside of alloy steel core and both spirally wound with blue asbestos yarn covering
2	0.15	0.40	0.009	0.026	0.012	
3	0.13	0.47	0.010	0.031	0.011	Lime on surface
4	0.13	0.45	0.005	0.032	0.010	Flux Coated
5	0.010–0.14	0.35–0.55	0.03 max.	0.035 max.	....	
6	0.06 max.	0.35 max.	0.04 max.	0.04 max.	0.08 max.	Flux Coated
7	0.06–0.12	0.20–0.45	0.05 max.	0.05 max.	0.05 max.	
8	0.15	0.45	0.011	0.030	Trace	
9	0.10–0.15	0.40–0.60	0.04 max.	0.04 max.	0.08 max.	Rod coated with paste to produce a reducing atmosphere
10	0.14	0.40	0.005	0.021	0.033	
11	0.12	0.48	0.012	0.021	0.010	
12	0.09	0.27	0.005	0.032	0.010	Alloy Coated
13	0.025	0.08	0.004	0.034	0.007	Flux Coated
14	0.10–0.15	0.40–0.60	0.04 max.	0.04 max.	0.04 max.	Heavy Flux Coating for AC welders
15	0.10–0.15	0.40–0.60	0.04 max.	0.04 max.	0.04 max.	Light Flux Coating for DC welders
16	0.13	0.44	0.012	0.021	0.007	
18	0.13	0.44	0.012	0.021	0.007	Rod coated with paste to produce a reducing atmosphere
22	0.12	0.48	0.012	0.021	0.010	Flux Coated.

chined away, leaving the section through the weld the same as through the parent metal.

Eighteen kinds of weld-rods were used. Two sets of six specimens each were made from some of the rods and one set of six each from the others. Where two sets of specimens were made from one kind of rod, one set was welded by a regular workman employed by the Chicago Bridge and Iron Works and one set by a welder employed by the company furnishing the rod.

The specimens were tested to determine the ultimate strength of the weld. In general, if a specimen broke outside of the weld the remaining specimens of that series had three holes drilled in the weld with a No. 30 drill (diameter = 0.128 in.), so as to reduce the section through the weld, before the other specimens of the series were tested. In two series a specimen with three holes failed outside of the weld. In these cases five holes were drilled in the remaining specimens of the series before they were tested.*

---

*The unit stresses reported for welds containing small holes is higher than would have been developed if it had been possible to break the welds without reducing the section with holes. For the unit stress at failure for a flat containing small holes on a transverse section, obtained by dividing the maximum load by the area of the transverse section through the holes, is greater than the unit stress at failure of a flat of the same material containing no holes. Six specimens of steel of structural grade were cut from the same bar, the finished section being 1½ in. x ½ in. Two specimens were without holes; two had three holes drilled with a No. 30 drill, nominal diameter 0.128 in., on the transverse section at the center, and two had five similar holes similarly located. The strength of the specimens, the average of two tests in each case, was 62 336, 70 846, and 70 895 lb. per sq. in., respectively. Holes are known to have less effect upon brittle than upon ductile material.

TABLE 5
SHOP LOG OF WELDS MADE BY CHICAGO BRIDGE AND IRON WORKS

		Series No.							
		2	3	4	10	11	12	13	18
First Bead	Inches of wire	59.	57.	62.	66.	57.	82.	67.5	56.5
	Av. Kw.	2.7	2.7	2.6	2.6	2.6	2 65	2.4	2.1
	Total Kw.-hr.	0.266	0.255	0.246	0.273	0.269	0.366	0.41	0.255
	Av. voltage	18.	19.	17.	18.	18.	20.	17.5	20.
	Av. current	150.	142.	153.	145.	145.	133.	137.	105.
	No. of breaks	5.	4.	4.	5.	4.	6.	6.	5.
	No. of freezes	3.	2	4.	1.	2.	0.	0.	6.
	Welding time, min.	5.9	5.67	5.9	6.3	6.2	8.3	10.3	7.3
Second Bead	Inches of wire	203.5	205.5	187.5	236.5	226	218.	204.5	214.5
	Av. Kw.	2.6	3.05	2.8	3.0	3.1	2.6	2.6	2.68
	Total Kw.-hr.	0.92	0.865	0.84	1.04	1.18	0.93	1.15	1.05
	Av. voltage	20.	19.	17.	18.	18.	17.	17.5	20.
	Av. current	130.	160.	165.	167.	172.	153.	149.	134.
	No. of breaks	16.	17.	14.	16.	18.	17.	16.	20.
	No. of freezes	12.	6.	4.	2.	11.	1.	5.	5.
	Welding time, min.	21.5	19.2	18.	20.8	22.8	21.6	26.6	23.6

The chemical composition and other characteristics of the rods are given in Table 4, and the shop log of the specimens welded by the Chicago Bridge and Iron Works is given in Table 5.

10. *Results of Tests.*—The ultimate strength of the specimens is given in Tables 6 and 7, Table 6 being for specimens welded by the Chicago Bridge and Iron Works, and Table 7 for specimens welded by the companies furnishing the weld-rods. The number of holes drilled through the weld to insure failure at the weld is indicated in the right-hand column of these tables. In obtaining the average strength of the welds, specimens were not included that broke outside of the weld unless their strength exceeded the average strength of those that broke in the weld. Table 8 is a summary of Tables 6 and 7. The strength of the specimens welded by the Chicago Bridge and Iron Works, the average value given in Table 6, is given in column 3. The same data for specimens welded by the companies furnishing the weld-rods are given in column 2. The uniformity of all specimens made with the same rod is worthy of attention. It is also interesting to note that the regular workmen in the employ of the Chicago Bridge and Iron Works produced welds that were as strong as those produced by welders employed by the companies furnishing the rod in practically all cases. The extremely high strength of the welds in series No. 1, 76 621 lb. per sq. in., is especially gratifying.*

---

*See note, bottom of page 28.

TABLE 6

STRENGTH OF WELDS MADE WITH RODS FROM VARIOUS COMPANIES

Welds all made by one welder employed by the Chicago Bridge and Iron Works.
Nominal section of all specimens 1.5 in. by 0.5 in. Unit stress is based on actual section before test.
Values marked with an asterisk were not included in the average.
All welds were of the V type.
Specimens broke in the weld unless otherwise noted.
Excess weld material was machined off making section at weld same as body of specimen.

Series No.	Specimen No.	Reduction of Area per cent	Ultimate Strength		Remarks
			Total	Lb. per sq. in.	
2	1	6.50	38 900	53 288	
	2	5.75	40 800	54 839	
	3	6.50	40 850	55 054	
	4	4.25	36 950	49 531	
	5	5 50	38 280	50 635	
	6	5 50	37 760	49 750	
	Av.	5.67		52 185	
3	1	5.50	38 750	51 667	
	2	7.00	43 440	58 153	
	3	7.00	42 500	56 366	
	4	5.00	40 490	53 629	
	5	7.50	41 600	54 783	
	6	7.75	42 560	55 634	
	Av.	6.63		55 039	
4	1	6 50	40 630	54 684	
	2	5 00	38 900	51 936	
	3	6 50	42 220	55 934	
	4	5 75	38 000	50 398	
	5	6.50	39 990	52 480	
	6	8 00	43 760	56 465	
	Av.	6.38		53 650	
10	1	4.75	37 520	51 186	
	2	5 00	39 790	52 563	
	3	5.50	38 080	49 843	
	4	6.00	42 480	55 602	
	5	7.50	42 530	56 034	
	6	7.00	42 240	56 021	
	Av.	5.96		53 542	
11	1	5.50	40 720	54 805	
	2	5.75	42 700	56 858	
	3	7.50	38 860	51 199	
	4	5.50	39 590	53 864	
	5	6.00	39 290	51 697	
	6	5.50	42 720	57 036	
	Av.	5.96		54 243	

Figure 19 shows the fractures in the specimens welded by the Chicago Bridge and Iron Works. Figures 20, 21, and 22 show the fractures for series 9, 15, and 18 welded by the companies furnishing the weld-rod. Figure 22 indicates that the material in the weld had a high ductility. This is of special interest since, for this series, the strength was high, 67 979 lb. per sq. in.*

These tests indicate that there are a number of weld-rods on the market with which a good journeyman welder can consistently make

---

*See note, bottom of page 28.

Table 6—*Concluded*

Series No.	Specimen No.	Reduction of Area per cent	Ultimate Strength		Remarks
			Total	Lb. per sq. in.	
12	1	5.50	38 630	50 963	
	2	6.50	36 920	49 161	
	3	6.50	34 500	46 000	
	4	7.25	39 080	52 037	
	5	5.50	37 960	49 947	
	6	9.00	41 970	55 079	
	Av.	6.04		50 531	
13	1	4.50	35 750	47 987	
	2	6.00	38 990	52 126	
	3	4.75	36 290	48 908	
	4	7.50	42 100	56 434	
	5	5.75	37 620	50 227	
	6	5.00	37 700	50 809	
	Av.	5.58		51 082	
14	1	....	42 350	54 928	
	2	....	41 780	53 290	
	3	....	42 690	54 730*	Broke outside of weld
	4	....	34 670	60 191	3–No. 30 holes out†
	5	....	33 800	57 679	3–No. 30 holes out
	6	....	29 550	50 341	3–No. 30 holes out
	Av.	....		55 286	
15	1	....	42 670	54 495*	Broke outside of weld
	2	....	34 320	57 583	3–No. 30 holes out†
	3	....	35 700	60 611	3–No. 30 holes out
	4	....	34 960	60 275	3–No. 30 holes out
	5	....	37 530	64 153	3–No. 30 holes out
	6	....	35 980	59 177	3–No. 30 holes out
	Av.	....		60 360	3–No. 30 holes out
16	1	6.50	38 340	51 671	
	2	5.50	38 670	51 423	
	3	6.25	40 040	53 316	
	4	9.00	44 310	59 317	
	5	6.50	42 670	58 054	
	6	7.25	42 440	56 814	
	Av.	6.83		55 099	
22	1	....	40 310	53 320	
	2	....	44 610	58 460	
	3	....	44 240	57 980	
	4	....	45 250	59 070	
	5	....	45 180	58 820	Broke outside of weld
	6	....	44 315	57 400	
	Av.	....		57 508	

†See note, bottom of page 28.

welds in ½-in. steel plates capable of developing a strength of 50 000 to 55 000 lb. per sq. in.

There were three rods designed to produce a reducing atmosphere over the molten metal; the values for the average strength of these rods, as given in Table 8, are 76 621,* 67 979, and 52 102 lb. per

---

*See note, bottom of page 28.

TABLE 7

STRENGTH OF WELDS MADE WITH RODS FROM VARIOUS COMPANIES

Welds made by company furnishing weld-rod.
Values marked with an asterisk were not included in the average.
All welds were of the V type.
Specimens broke in the weld unless otherwise noted.
Excess weld material was machined off making section at weld same as body of specimen.

Series No.	Specimen No.	Dimensions Before Test			Ultimate Strength		Remarks
		Width	Thick.	Area	Total	Lb. per sq. in.	
1	1	1.499	0.519	0.779	39 130	50 231*	Broke outside of weld
	2	1.496	0.523	0.582	39 360	67 630*	3-No. 30 holes out. Broke o.s. of weld
	3	1.500	0.521	0.448	36 390	81 227	5-No. 30 holes out†
	4	1.505	0.538	0.465	35 750	76 880	5-No. 30 holes out
	5	1.498	0.518	0.444	34 640	78 018	5-No. 30 holes out
	6	1.498	0.518	0.444	31 240	70 360	5-No. 30 holes out
	Av.					76 621	5-No. 30 holes out
2	1	1.511	0.495	0.748	35 300	47 192	
	2	1.512	0.500	0.756	38 230	50 568	
	3	1.507	0.499	0.752	38 380	51 037	
	4	1.503	0.492	0.739	36 590	49 512	
	5	1.506	0.509	0.767	39 500	51 500	Broke outside of weld
	6	1.506	0.480	0.723	27 080	37 455	
	Av.					47 877	
3	1	1.502	0.515	0.774	30 810	39 806	
	2	1.503	0.496	0.745	34 550	46 375	
	3	1.500	0.506	0.759	36 540	48 142	
	4	1.504	0.504	0.758	37 460	49 419	
	5	1.499	0.501	0.751	37 820	50 359	
	6	1.499	0.514	0.770	31 720	41 194	
	Av.					45 882	
4	1	1.508	0.520	0.784	32 930	42 002	
	2	1.510	0.512	0.773	29 110	37 658	
	3	1.508	0.502	0.757	32 860	43 408	
	4	1.509	0.517	0.780	35 060	44 948	
	5	1.507	0.514	0.775	33 820	43 638	
	6	1.512	0.525	0.794	40 140	50 554	
	Av.					43 701	
5	1	1.508	0.478	0.721	37 640	52 205	
	2	1.508	0.481	0.725	44 940	61 986	
	3	1.509	0.491	0.741	41 180	55 573	
	4	1.510	0.495	0.747	41 050	54 953	
	5	1.506	0.482	0.726	37 900	52 204	
	6	1.509	0.478	0.721	40 650	56 380	
	Av.					55 550	
6	1	1.509	0.476	0.718	36 330	50 600	
	2	1.506	0.475	0.715	41 140	57 538	
	3	1.509	0.490	0.739	35 180	47 605	
	4	1.508	0.470	0.709	41 710	58 829	
	5	1.509	0.476	0.718	45 000	62 674	
	6	1.506	0.492	0.741	38 730	52 267	
	Av.					54 918	
7	1	1.508	0.483	0.728	41 730	57 321	
	2	1.504	0.482	0.725	42 900	59 173	Broke ouside of weld
	3	1.508	0.483	0.728	41 820	57 445	3-No. 30 holes out†
	4	1.507	0.473	0.713	36 710	51 487	3-No. 30 holes out
	5	1.507	0.482	0.726	41 670	57 396	3-No. 30 holes out
	6	1.508	0.493	0.743	38 910	52 369	3-No. 30 holes out
	Av.					55 865	
8	1	1.505	0.515	0.775	41 070	52 993	
	2	1.498	0.502	0.752	40 760	54 202	
	3	1.508	0.503	0.565	30 880	54 654	
	4	1.506	0.503	0.564	31 800	56 383	
	5	1.504	0.500	0.560	30 660	54 750	
	6	1.500	0.501	0.559	32 340	57 853	
	Av.					55 326	

†See note, bottom of page 28.

TABLE 7—*Concluded*

Series No.	Specimen No.	Dimensions Before Test			Ultimate Strength		Remarks
		Width	Thick.	Area	Total	Lb. per sq. in.	
9	1	1.485	0.498	0.740	42 200	57 027	Broke oustide of weld
	2	1.512	0.501	0.758	39 940	52 691	
	3	1.407	0.498	0.701	34 180	48 759	
	4	1.559	0.497	0.775	43 200	55 742	Broke outside of weld
	5	1.516	0.475	0.710	32 870	46 295	
	Av.					52 102	
10	1	1.507	0.531	0 800	34 250	42 812	
	2	1.508	0.523	0.789	39 540	50 114*	Broke outside of weld
	3	1.506	0.535	0.806	39 190	48 622	
	4	1.507	0.525	0 590	34 450	58 389	3–No. 30 holes out†
	5	1.506	0.530	0.595	36 650	61 596	3–No. 30 holes out
	6	1.508	0.525	0.590	31 870	54 016	3–No. 30 holes out
	Av.					53 087	
11	1	1.506	0.518	0.780	34 090	43 705	
	2	1.503	0.500	0.752	35 170	46 768	
	3	1.503	0.508	0.764	32 800	42 931	
	4	1.504	0.506	0.761	33 570	44 113	
	5	1.506	0.508	0.765	35 710	46 680	
	6	1.504	0.517	0.778	28 710	36 902	
	Av.					43 516	
12	1	1.505	0.524	0.789	39 760	50 393*	Broke outside of weld
	2	1.504	0.523	0.787	39 510	50 203	
	3	1 504	0.520	0.782	39 810	50 908*	Broke outside of weld
	4	1.503	0.517	0.579	36 570	63 160	3–No. 30 holes out†
	5	1.501	0.519	0.580	38 600	66 551	3–No. 30 holes out
	6	1.502	0.518	0.579	36 910	63 747	3–No. 30 holes out
	Av.					60 915	
13	1	1.508	0.510	0.769	38 630	50 234*	Broke outside of weld
	2	1.508	0.511	0.771	38 690	50 181*	Broke outside of weld
	3	1.504	0.513	0.772	38 700	50 130*	Broke outside of weld
	4	1.504	0.525	0.588	31 060	52 823	3–No. 30 holes out†
	5	1.503	0.515	0.576	32 420	56 285	3–No. 30 holes out
	6	1.507	0.530	0.595	32 660	54 890	3–No. 30 holes out
	Av.					54 666	
14	1	1.507	0.454	0.684	40 840	59 707	
	2	1.505	0.475	0.715	41 250	57 692	
	3	1.505	0.495	0.745	33 720	45 262	
	4	1.508	0.497	0.749	41 460	55 355*	Broke outside of weld
	5	1.505	0.505	0.566	34 470	60 900	3–No. 30 holes out†
	6	1.509	0.485	0.546	29 340	53 736	3–No. 30 holes out
	Av.					55 442	
15	1	1.505	0.509	0.766	41 020	53 550	
	2	1.511	0.517	0.781	41 530	53 175*	Broke outside of weld
	3	1.512	0.498	0.753	35 770	47 503	
	4	1.507	0.491	0.551	36 930	67 023	3–No. 30 holes out†
	5	1.507	0.500	0.562	28 520	50 747	3–No. 30 holes out
	6	1.508	0.522	0.587	32 330	55 076	3–No. 30 holes out
	Av.					54 780	
18	1	1.510	0.546	0.824	40 390	49 017*	Broke outside of weld
	2	1.500	0.549	0.824	39 740	48 228*	Broke outside of weld
	3	1.514	0.542	0.612	39 630	64 755*	3–No. 30 holes out. Broke† outside of weld
	4	1.510	0.535	0.465	31 460	67 656	5–No. 30 holes out
	5	1.512	0.552	0.835	39 410	47 198*	Broke outside of weld
	6	1.508	0.556	0.483	32 990	68 302	5–No. 30 holes out
	Av.					67 979	

†See note, bottom of page 28.

Table 8

Summary of Tests

Strength of Welds Made with Various Weld-Rods.

Series No.	Strength of Weld, lb. per sq. in.	
	Weld Made by	
	Company Furnishing Rod	Chicago Bridge and Iron Works
1	76 621 - 4*†	....
2	47 877 - 6	52 183 - 6*
3	45 882 - 6	55 039 - 6
4	43 701 - 6	53 650 - 6
5	55 550 - 6	....
6	54 918 - 6	....
7	55 865 - 6†	....
8	55 326 - 6	....
9	52 102 - 5	....
10	53 081 - 5†	53 542 - 6
11	43 516 - 6	54 243 - 6
12	60 915 - 4†	50 531 - 6
13	54 666 - 3†	51 082 - 6
14	55 442 - 5†	55 286 - 5
15	54 780 - 5†	60 360 - 5
16	....	55 099 - 6
18	67 979 - 2†	....
22	....	57 508

*Number of tests averaged

†See note, bottom of page 28.

sq. in. for rods 1, 18, and 9, respectively. The highest value for an uncoated rod was 60 915 lb. per sq. in., for rod 12.* In so far as any conclusions may be reached from these tests, the data indicate that a rod designed to produce a reducing atmosphere over the molten metal may be, but is not necessarily, superior to an uncoated rod. It would appear that, before the superiority of a make of rod can be accepted, tests should be made upon welds from that rod.

VI. Summary

11. *Summary.*—Of the welds tested, the V type seems to be the best for making butt-joints in ½-in. plates.

In the study of various makes of weld-rods, sixty-six specimens were tested that had been welded by the same workman, a journeyman welder employed by the Chicago Bridge and Iron Works, six specimens being made from each of eleven kinds of rods. The weakest specimen developed 46 000 lb. per sq. in., and the next weakest 48 000 lb. per sq. in. The lowest average for any one set of six specimens

---

*These welds were made by the company furnishing the rod.

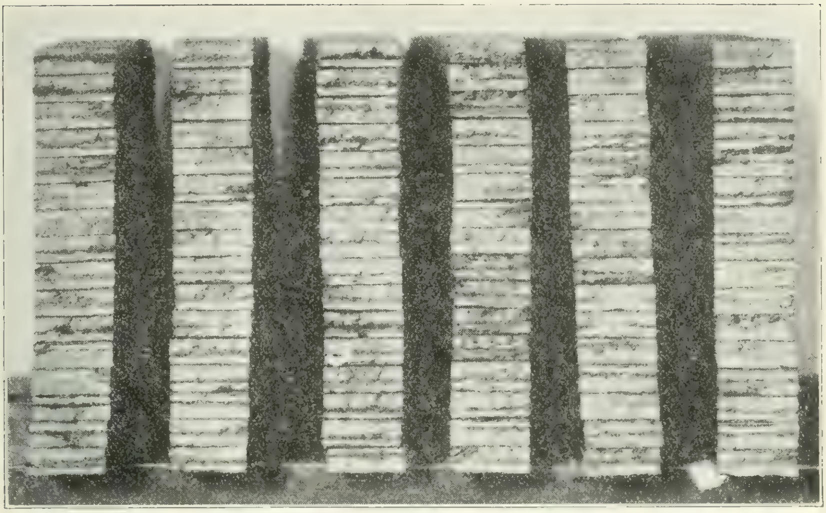


Fig. 19. Fractured Sections of Specimens Welded by Chicago Bridge and Iron Works

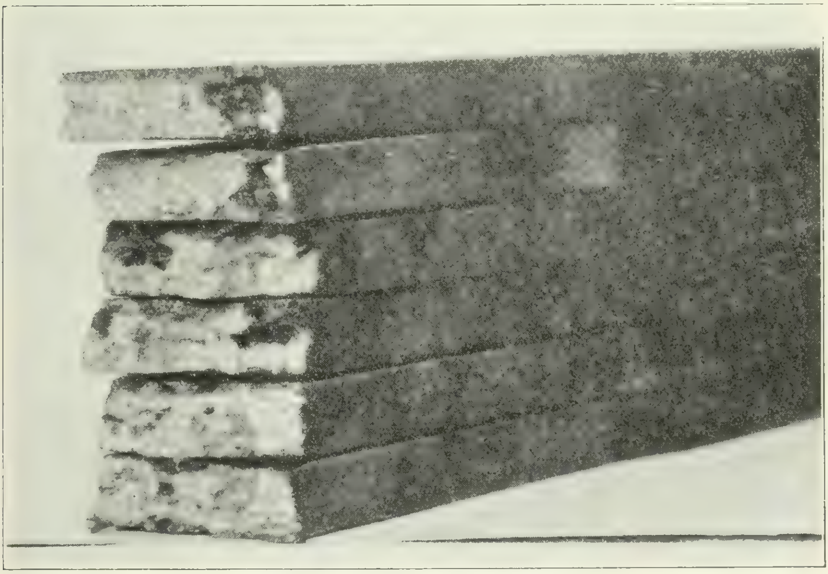


Fig. 20. Fracture Section, Series 9

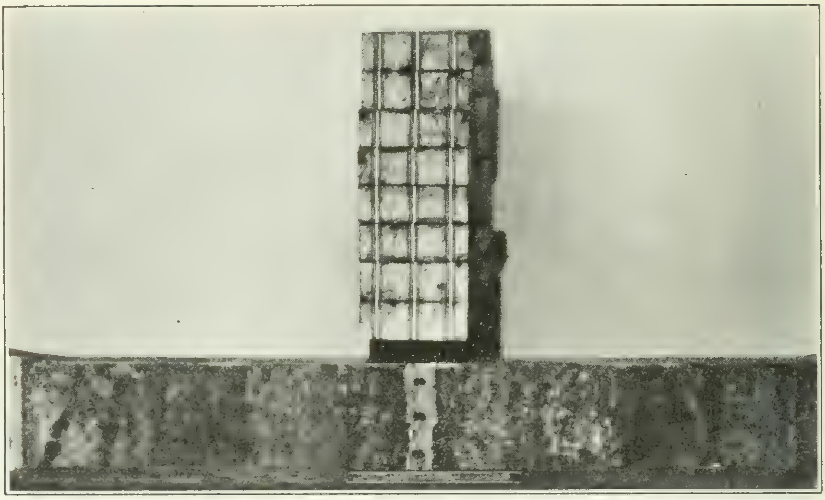


FIG. 21. FRACTURE SECTION, SERIES 15

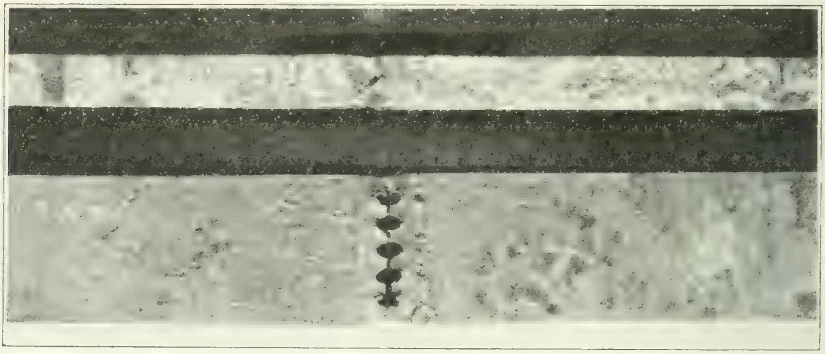


FIG. 22. FRACTURE SECTION, SERIES 18

made from the same kind of rod was 50 531 lb. per sq. in., and the average for the 66 specimens was 54 410 lb. per sq. in. All welds were of the V type, and welds for all specimens had the excess material machined away so that the section was of the same thickness through the weld as through the body of the specimen. The specimens received no heat treatment after the welds were made.

The strengths of the specimens welded by the same workman, but made with various uncoated rods, were fairly consistent. The lowest average for any one rod was 50 531 lb. per sq. in., and the highest average for any rod, 60 360 lb. per sq. in. The specimens made from the three rods designed to produce a reducing atmosphere over the molten metal had ultimate strengths of 76 621,* 67 979,* and 52 102 lb. per sq. in., respectively. In so far as any conclusions may be reached from these tests, the data indicate that a rod designed to produce a reducing atmosphere over the molten metal may be, but is not necessarily, superior to an uncoated rod. It would appear that before the superiority of a particular make of rod can be accepted, tests should be made upon welds from that rod.

The strength of the all-weld specimens made of uncoated rods was 57 500 lb. per sq. in. when the beads were laid longitudinally with the specimens, and 43 314 lb. per sq. in. when the beads were laid transversely to the specimens. The corresponding values for specimens made of rods designed to produce a reducing atmosphere were 57 300 and 52 375 lb. per sq. in., respectively. The elongation in 8 inches and the reduction in area for specimens made from uncoated rods were 8.36 and 10.29 per cent, respectively, for specimens with longitudinal beads, and 2.69 and 6.28 per cent for those with transverse beads. The corresponding values for specimens made from rods designed to produce a reducing atmosphere were 12.8 and 25.3 per cent, and 8.6 and 23.62 per cent, respectively. The modulus of elasticity in lb. per sq. in. for specimens made from uncoated rods was 28 400 000 for specimens with longitudinal beads, and 27 508 000 for specimens with transverse beads. The corresponding values for specimens made from a rod designed to produce a reducing atmosphere were 27 600 000 and 26 800 000, respectively.

The six specimens containing lap-joints welded with a rod not designed to produce a reducing atmosphere all broke outside of the weld, the average strength being 57 605 lb. per sq. in., a value just slightly greater than the strength of the control specimens cut from the plates welded together.

---

*See note, bottom of page 28.

UNIVERSITY OF ILLINOIS
THE STATE UNIVERSITY
URBANA

Harry Woodburn Chase, Ph.D., LL.D., President

The University includes the following departments:

The Graduate School

The College of Liberal Arts and Sciences (Curricula: General with majors, in the Humanities and the Sciences; Chemistry and Chemical Engineering; Pre-legal, Pre-medical, and Pre-dental; Pre-journalism, Home Economics, Economic Entomology, and Applied Optics)

The College of Commerce and Business Administration (Curricula: General Business, Banking and Finance, Insurance, Accountancy, Railway Administration, Railway Transportation, Industrial Administration, Foreign Commerce, Commercial Teachers, Trade and Civic Secretarial Service, Public Utilities, Commerce and Law)

The College of Engineering (Curricula: Architecture, Ceramics; Architectural, Ceramic, Civil, Electrical, Gas, General, Mechanical, Mining, and Railway Engineering; Engineering Physics)

The College of Agriculture (Curricula: General Agriculture; Floriculture; Home Economics; Landscape Architecture; Smith-Hughes — in conjunction with the College of Education)

The College of Education (Curricula: Two year, prescribing junior standing for admission — General Education, Smith-Hughes Agriculture, Smith-Hughes Home Economics, Public School Music; Four year, admitting from the high school—Industrial Education, Athletic Coaching, Physical Education. The University High School is the practice school of the College of Education)

The School of Music (four-year curriculum)

The College of Law (three-year curriculum based on a college degree, or three years of college work at the University of Illinois)

The Library School (two-year curriculum for college graduates)

The School of Journalism (two-year curriculum based on two years of college work)

The College of Medicine (in Chicago)

The College of Dentistry (in Chicago)

The School of Pharmacy (in Chicago)

The Summer Session (eight weeks)

Experiment Stations and Scientific Bureaus: U. S. Agricultural Experiment Station; Engineering Experiment Station; State Natural History Survey; State Water Survey; State Geological Survey; Bureau of Educational Research.

The Library collections contain (May 1, 1930) 836,496 volumes and 221,800 pamphlets.

For catalogs and information address

THE REGISTRAR
Urbana, Illinois